

1 **The effects of classroom noise on the reading comprehension of adolescents**

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20 Running title: Effects of classroom noise on reading

1

2 **ABSTRACT**

3 An investigation has been carried out to examine the impact of different levels of classroom  
4 noise on adolescents' performance on reading and vocabulary-learning tasks. A total of 976  
5 English high school pupils (564 aged 11 to 13 years and 412 aged 14 to 16 years) completed  
6 reading tasks on laptop computers while exposed to different levels of classroom noise  
7 played through headphones. The tasks consisted of reading science texts, which were  
8 followed by multiple-choice questions probing comprehension and word learning. Number of  
9 questions attempted, times taken to read the texts and to answer questions were recorded, as  
10 well as correct answers to different types of question. The study consisted of two similar  
11 experiments, the first comparing performance in classroom noise at levels of 50 dB  $L_{Aeq}$  and  
12 70 dB  $L_{Aeq}$ ; and the second at levels of 50 dB  $L_{Aeq}$  and 64 dB  $L_{Aeq}$ . The results showed that  
13 the performance of all pupils was significantly negatively affected in the 70 dB  $L_{Aeq}$   
14 condition, for the number of questions attempted and the accuracy of answers to factual and  
15 word learning questions. It was harder to discern effects at 64 dB  $L_{Aeq}$ , this level of noise  
16 having a detrimental effect upon the older pupils only.

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20 PACS numbers: 43.50Jh, 43.50Qp, 43.50 Rq, 43.55Hy

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1 **I INTRODUCTION**

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The detrimental effects on pupils of noise and poor acoustic design in schools have been of concern for many years. In an attempt to mitigate these effects guidelines and regulations governing the acoustic design of schools have been introduced in many countries. The most comprehensive of these are those introduced in the USA (American National Standards Institute, 2010) and UK (Department for Education, 2015), both of which specify suitable background noise levels for classrooms of different sizes and types. The guidelines also include criteria for sound insulation and reverberation time, with the aim of reducing noise in the classroom to a minimum.

Despite the introduction of standards, surveys have shown that noise levels in classrooms can still be high, the main sources of noise being pupils themselves. An extensive noise survey of secondary schools in England also showed that the level of noise in occupied classrooms was related to the unoccupied background level (Shield *et al*, 2015). Many studies have shown that excessive noise causes annoyance to pupils and that high noise levels affect performance (Shield and Dockrell, 2010). However, it is not known at what level detrimental effects of noise on performance start to occur.

By the time, pupils enter high school, much of teaching and learning occurs through written text in the form of books, worksheets, online material or instructions. Understanding the factors that negatively impact on pupils' speed and accuracy of accessing written materials is an important prerequisite to enhance attainment. The current study examines the effects of internal classroom noise, primarily classroom chatter, at different levels on high school pupils' ability to comprehend and learn from written texts.

## 1 II. BACKGROUND

### 2 A. Impact of noise on teaching and learning

3 Despite the widespread introduction of acoustical guidelines for schools, acoustical surveys  
4 of high schools show that they are often very noisy places. A recent comprehensive study of  
5 English high school classrooms found that occupied noise levels varied between 45 dB and  
6 77 dB  $L_{Aeq}$ , depending on the age and number of pupils and the classroom activity, with an  
7 average lesson noise level of 64 dB  $L_{Aeq}$  (Shield *et al*, 2015). Pupils are sensitive to the  
8 disruptive effects of classroom noise: high levels of disturbance and annoyance are reported  
9 by pupils in schools with high outdoor and indoor noise levels (Avsar and Gonullu, 2010;  
10 Skarlatos and Manatakis, 2003), other students talking being cited as particularly disturbing  
11 (Connolly *et al*, 2013; Astolfi and Pellerey, 2008).

12

13 In addition to causing annoyance, noise in the classroom can affect teaching and learning.  
14 Teaching time is often lost due to interruption, and excessive noise levels interfere with the  
15 transmission of the teacher's voice (Crook and Langdon, 1974; Bronzaft and McCarthy,  
16 1975; Astolfi and Pellerey, 2008). Younger learners, between the ages of six and 12, are more  
17 severely affected by adverse listening conditions and require more favorable speech-to-noise  
18 ratios than adults in order to accurately identify speech in noisy conditions, especially when  
19 room reverberation times are long (Neuman *et al*, 2010). The sound of other learners' chatter  
20 and noise coming into the classroom from corridors and nearby classrooms are identified as a  
21 major determinant of classroom noise by pupils in elementary schools (Dockrell and Shield,  
22 2004) and high schools (Enmarker and Boman, 2004; Astolfi and Pellerey, 2008; Connolly *et*  
23 *al*, 2013), and by university students (Kennedy *et al*, 2006). In addition to creating adverse  
24 listening conditions, noise can disrupt pupils' ability to learn from written texts.

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## 1 **B. Impact of noise on reading comprehension**

2 Laboratory studies have shown that processes involved in serial recall of word lists are  
3 disrupted by unattended speech and speech-like sounds, a phenomenon known as the  
4 irrelevant sound effect (ISE) (Jones *et al*, 1992; Macken *et al*, 1999; Salamé and Baddeley,  
5 1987; Beaman, 2005). Two mechanisms have been posited to explain noise interference with  
6 short-term memory (Hughes, Vachon and Cowan, 2007): the deviation effect and  
7 interference by process. In the first instance poorer recall in noise is explained by unexpected  
8 changes in the irrelevant speech which divert attention away from the task, such as  
9 remembering a list of words, resulting in poorer performance. Alternatively, it is suggested  
10 that changes in the irrelevant speech are processed automatically, before being subjected to  
11 attentional processes, and in this way interfere with the rehearsal of the to-be-remembered  
12 items, which in turn negatively impacts on recall. Developmental investigations of the ISE  
13 have found that children are more susceptible to auditory distraction than adults (Elliott 2002;  
14 Meinhardt-Injac *et al*, 2015; Klatt *et al*, 2010) and that these effects are largest when the  
15 noise stream contains unexpected items compared to predictable sound sources, suggesting  
16 that children are more susceptible to the ISE because of their immature attentional abilities  
17 (Joseph *et al*, 2018).

18  
19 While the existence of the ISE is well-established, demonstrations of irrelevant sound  
20 disrupting reading comprehension have been less consistent. In laboratory studies with adults,  
21 some studies have found reading comprehension is negatively affected by background noise,  
22 with irrelevant speech causing the greatest disruption (Banbury and Berry, 1998; Martin *et al*,  
23 1988; Oswald *et al*, 2000; Sorqvist *et al*, 2010). Others have found no evidence of irrelevant  
24 speech negatively impacting on adults' reading comprehension compared to silence (Boyle  
25 and Coltheart, 1996). However, outside of the laboratory, chronic exposure to aircraft noise

1 at school has been shown to be associated with impaired reading comprehension in  
2 elementary school children (Bronzaft and McCarthy, 1975; Clark *et al*, 2005; Stansfeld *et al*,  
3 2005; Clark *et al*, 2013; Klatter *et al*, 2017), indicating that environmental noise has a serious,  
4 negative impact on the processes involved in reading. In order to further examine the effects  
5 of different types of noise and the types of task upon which they have most impact, several  
6 studies have investigated the effects of noise from different sources on reading in schools  
7 using exposure to simulated noise sources in classrooms. Shield and Dockrell, (2008) found  
8 that primary school children's reading and mathematics were impaired by classroom babble  
9 compared to quiet conditions, and studies with high school pupils have found negative effects  
10 of speech-like noise and road traffic noise on recall of text (Hygge *et al*, 2003; Sörqvist,  
11 2010). However, other studies have failed to find an effect of noise exposure in the  
12 classroom on adolescents' performance on reading tasks (Hygge, 2003; Ljung *et al*, 2009).

13

14 Reading comprehension is a multi-component skill, which draws upon a range of cognitive  
15 resources (Hannon and Daneman, 2001; Oakhill *et al*, 2003). Accurate reading of individual  
16 words involves both word decoding and retrieval of their meaning from the mental lexicon.  
17 Building a coherent representation of the meaning of a text requires integration of  
18 information between sentences and the generation of inferences about states of affairs that are  
19 not explicitly detailed in the text (Cain *et al*, 2001; Graesser *et al*, 1994). Irrelevant sound  
20 may disrupt the short-term memory processes involved in reading (Hughes and Jones, 2001;  
21 Tremblay *et al*, 2000), and irrelevant speech has been shown to cause semantic interference  
22 resulting in poorer reading comprehension in adolescents (Sörqvist, 2010). However, little is  
23 known about the ways in which realistic classroom noise impacts aspects of reading  
24 comprehension in adolescents, such as inference or the ability to learn from text.

1 High school students are required to access progressively more complex reading materials  
2 and encounter words that are increasingly abstract and low in frequency of occurrence with  
3 non-literal meanings (Nagy *et al*, 1993; Nippold *et al*, 1988). By the time students are in high  
4 school vocabulary development is primarily supported by reading. Whilst there is evidence  
5 that noise interferes with oral vocabulary acquisition in toddlers (Capone and McGregor,  
6 2005), on older students' listening comprehension (Bradlow *et al*, 2003; Klatte *et al*, 2010)  
7 and the ability to identify words correctly (Elliott, 1979; Elliott *et al*, 1979; Neuman *et al*,  
8 2010), there have been no investigations of adolescents' word learning in noisy classrooms.  
9 Given the demands placed on working memory in developing new vocabulary it is predicted  
10 that poor classroom acoustics will reduce the acquisition of new vocabulary from written  
11 texts.

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### 14 **III. THE CURRENT STUDY**

15 The aim of the current study was to examine the impact of typical levels of classroom noise  
16 on the reading performance of high school pupils aged between 11 and 16 years, and thereby  
17 to investigate at what level of noise a negative impact on reading might occur; in what ways  
18 the processes involved in reading are affected; and whether noise has a differential impact  
19 upon pupils of different ages. Previous studies have found that younger children are more  
20 susceptible to the negative effects of noise than older pupils (Elliott and Briganti, 2012;  
21 Klatte *et al*, 2010; Meinhardt-Injac *et al*, 2015).

22

23 The reading test was part of a test battery that also included tests of numeracy, speed of  
24 processing and short-term memory. The tests were programmed using E-Prime version  
25 2.0.8.9 software. For the reading tests, bespoke science texts were created from science news  
26 articles and read silently by pupils on individual laptop computers, while classroom noise was

1 presented over headphones at levels that reflected the typical range of noise levels measured  
2 in English high school classrooms. Comprehension and word learning were assessed by  
3 multiple-choice questions.

4

5 As well as accuracy in answering questions, it is possible that the time taken to read each text  
6 and the time taken to respond to each question (the ‘response latency’) may be affected by  
7 noise. Typically, readers are able to re-read sections of text they did not understand on first  
8 reading or to vary their speed when reading passages that are difficult to process (Cain,  
9 2010). Hence, the ability to reread and alter reading speed may reduce the impact of noise on  
10 the processing of written text. Reading speed and response latency may therefore offer a valid  
11 way to measure the effects of noise in cases where accuracy measures may not be sufficiently  
12 sensitive to identify changes (Jackson and McClelland, 1975). These measures also permit  
13 discrimination between the ways in which background noise might affect reading.

14 Unfavorable noise levels might produce a speed-accuracy trade off, such that reduced  
15 accuracy is reflected in shorter reading times and response latencies. Alternatively, noise  
16 might affect reading comprehension because screening out the noise places an additional load  
17 on cognitive processes, resulting in slower reading, longer response latencies and poorer  
18 accuracy (Sweller, 1988). Therefore, reading and response times were measured as described  
19 in Section IV.

20

21 The experimental methods and procedures, which are described in Section IV, were approved  
22 by the Psychology Ethics Committee of the Institute of Education, London. Approval for  
23 pupils to participate in the study was given by the head teachers of all participating schools,



1 and by parents/guardians of individual pupils. In addition, all participating pupils were  
2 offered the opportunity to withdraw at any point during the testing.

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#### 4 **IV. METHODOLOGY**

##### 5 **A. Overall design**

6 Two experiments were carried out with two different groups of pupils. In each experiment  
7 one group of participants completed tasks in two different noise conditions. Experiment 1  
8 compared pupils' performance in noise levels of 50 dB  $L_{Aeq}$  and 70 dB  $L_{Aeq}$  and Experiment  
9 2 compared pupils' performance in noise levels of 50 dB  $L_{Aeq}$  and 64 dB  $L_{Aeq}$ . The noise  
10 levels were chosen to represent typical levels measured during an extensive noise survey of  
11 occupied classrooms in English secondary schools (Shield *et al*, 2015), which found 64 dB  
12  $L_{Aeq}$  to be the average level measured across all lessons, while 50 dB  $L_{Aeq}$  and 70 dB  $L_{Aeq}$   
13 represent the lower and upper ranges of levels measured in lessons.

14

15 The materials and test procedure for each experiment, as described in sections IVC to IVE,  
16 were the same. In each experiment, participants completed two different test sessions  
17 separated by two academic school weeks, experiencing one noise condition in the first test  
18 and a different noise condition in the second test. The order of the noise conditions was  
19 counterbalanced across the group, with half of the participants in each year group receiving  
20 the 50 dB  $L_{Aeq}$  condition first and half receiving the louder (64 dB  $L_{Aeq}$  or 70 dB  $L_{Aeq}$ )  
21 condition first, to allow for learning effects in the second test. In addition, two sets of reading  
22 materials were counterbalanced across conditions to avoid familiarity with the texts.

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1 **B. Participants**

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3 A total of 976 pupils aged 11 to 16 years of age (Year 8 to Year 11) , from seven schools,  
4 participated in the study, 669 from seven schools in Experiment 1 and 307 different pupils  
5 from four of those schools in Experiment 2. The schools reflected the national intake of high  
6 school pupils in England. Pupil roll numbers were slightly larger than the national averages  
7 (mean = 1052; national mean = 910). Numbers of pupils with a statement of special  
8 educational needs (mean = 4.3; national mean = 4.1), and eligible for free school meals (an  
9 index of poverty) (mean = 27.4; national mean = 29.1) were all commensurate with national  
10 data. Numbers of pupils reporting English as an additional language (mean = 11.66) was  
11 below the national average (16.1) reflecting the school catchment areas.

12

13 In the UK children enter school at the age of five and continue with their peer group until  
14 school leaving age (16 at the time of the study). For the purposes of statistical analysis, and  
15 to examine the impact of noise on different age groups, the participants were divided into two  
16 age groups, 11 to 13 years (Year 8 to Year 9) and 14 to 16 years (Year 10 to Year 11),  
17 reflecting UK national school age groupings. A breakdown of the age groups in the two  
18 experiments is shown in Table I.

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21 **C. Noise stimuli**

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23 The noise stimulus was constructed from recordings of the activity noise during science and  
24 history lessons in cellular classrooms, with pupils aged 12 to 13 years. The recordings  
25 consisted of unidentifiable speech (babble) and sound events (e.g. chair scrapes, pencil drops,  
26 movement). Eight unique but acoustically identical segments of recording were combined to  
27 create a noise stimulus with a total duration of 4 minutes 40 seconds. Filters were applied to

1 the signal to correct for the frequency response of the headphones and ensure that calibrated  
2 dB levels were reproduced faithfully.  
3  
4 To determine the frequency response of the Beyerdynamic DT100 headphones, they were  
5 placed onto a B&K 4100 Head And Torso Simulator (HATS). A three minute white noise  
6 signal was fed to the headphones from one of the task laptops to ensure that the entire  
7 reproduction system was measured. This white noise signal was recorded 16 times with the  
8 headphones placed on the HATS in different positions to simulate real life headphone  
9 placement variation between subjects. This process was repeated for 4 headsets to account for  
10 headphone hardware variations. These 64 recorded white noise signals were averaged and  
11 the differences between the average and the input white noise signal was calculated. From  
12 this a filter bank was created to compensate for the headphones' frequency response at each  
13 ear. A combination of free-field and diffuse-field corrections were further applied to the filter  
14 bank to account for the head and ear effects at different frequencies on measured sound  
15 pressure levels at the ear.  
16  
17 To calibrate the HATS for level, an 84 dBA white noise signal was measured at 3 m from a  
18 Genelec 8030A loudspeaker using a calibrated type 1 Svantek 959 sound level meter (SLM)  
19 in a regular classroom setting. The SLM was replaced with the HATS, whose microphone  
20 output was adjusted to also read 84 dBA. The filter bank was then applied to the test signals.  
21 These filtered test signals were played back through the headphones placed on the HATS.  
22 The  $L_{Aeq}$  over 5 minutes was measured for each test signal and the gains adjusted to meet the  
23 required level of 70 dBA. The gain was reduced by 20 dB to create the 50 dBA test signals.  
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1 **D. Reading task**

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3 The reading task was an adaptation of a self-paced reading paradigm (O'Brien *et al*, 1985).

4 Two sets of materials were developed, each consisting of four articles adapted from science

5 news stories on children's science education websites. All articles were adapted to be 160

6 words in length and contain an average of 1.2 polysyllabic words per sentence. The average

7 reading age of the articles was established as being between 11 and 12 years using three

8 established techniques of calculating reading age. Five multiple-choice questions

9 accompanied each article, assessing factual information contained explicitly in the text (two

10 questions); ability to infer information not explicitly stated in the text (two questions); and

11 learning of a single polysyllabic word contained in the title page of each text (one question).

12 An example of a text and questions is shown in the Appendix.

13

14 **E. Test procedure**

15

16 Test sessions took place in the pupils' usual science room under the supervision of a teacher

17 and two experimenters. An experimenter gave verbal introductions about the task and then

18 instructed participants to enter their names and ages onto the laptops. Responses were

19 anonymized once data from the two test sessions had been combined. Before starting the task,

20 participants completed an animated tutorial installed on the laptop that demonstrated the

21 procedure, and were given an opportunity to ask any questions about the test before the task

22 began.

23

24 All students completed the articles in a fixed order, starting with the easiest (average reading

25 age 11) and progressing to the most difficult (average reading age 12). Each article was

26 divided into three sections of text, of approximately equal length. At the start of each article,

27 participants read a title page featuring a polysyllabic word describing the subject matter of the

1 article, along with an explanation of its meaning. For example, ‘Selenology: The Study of the  
2 Moon’. Each section of text was followed by one or two questions that had to be answered  
3 before proceeding to the next section (see the Appendix). Five multiple-choice response  
4 options were presented on the screen below each question. Questions 1 and 2 were factual  
5 questions, questions 3 and 4 were inferential and question 5 assessed understanding of the  
6 novel word. The position of correct responses was randomized. In summary, each article was  
7 presented in the following sequence: Title page (containing science word tested  
8 subsequently); Text section 1, Question 1 (factual); Text section 2, Question 2 (factual),  
9 Question 3 (inferential); Text section 3, Question 4 (inferential), Question 5 (word learning).  
10 Progress through the test was achieved by pressing the space bar to advance to the next item.  
11  
12 When the three text sections and questions from each article had been completed, participants  
13 progressed onto the next article. The reading task was time-limited to four minutes in total,  
14 timed from initiation of the first title page. If the time limit was reached when participants  
15 were halfway through a section of text, they were permitted to complete that section and its  
16 associated questions and these responses were included in the analysis. After reaching the  
17 time limit and completing the last question for that section, participants were presented with a  
18 screen containing the comment ‘That’s it, all done’.  
19  
20 Response latencies for all questions and the reading time for each section of text were  
21 recorded automatically by the E-prime software. Timing for each item was commenced when  
22 the spacebar was pressed to advance to that item and terminated when it was pressed to  
23 advance to the next item.

24

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1 **F. Data analysis**

2 The number of correct responses for each question type was calculated for each pupil.  
3 Performance for all questions was assessed using the number of correct responses for each  
4 question type, averaged across all pupils. Mean article reading times were calculated by  
5 averaging participants' time to read the ~50 word sections of text in milliseconds, each section  
6 of text being timed from the point at which participants cued the presentation of the text to the  
7 point at which they cued the presentation of the subsequent questions; this provided a measure  
8 of reading speed. The total number of sections to be averaged depended on the speed with  
9 which individual pupils progressed through the task, such that pupils who read the text more  
10 quickly completed more sections of the task. To control for unexplained erroneous responses,  
11 response latencies for correct answers only were analyzed (Fazio, 1990). To prevent data  
12 attrition, randomly missing data points were replaced with the mean of the nearest two data  
13 points (Graham, 2009). Mean latencies for each type of question and article reading times were  
14 logarithmically transformed to correct for violations of assumptions of normality in the  
15 analysis.

16  
17 Multivariate analysis of variance (MANOVA) using Pillai's trace was used to investigate the  
18 effect of classroom noise level on the number of questions attempted, the number of correct  
19 responses (response accuracy) and the log-transformed reading times and response latencies.  
20 Both age group and noise conditions were examined as between group variables to investigate  
21 possibly different impacts of the two noise levels on the two age groups. Analysis of variance  
22 (ANOVA) was used to further analyse effects of noise condition on the recorded response data.  
23 A second MANOVA was used to examine whether order of noise conditions might have  
24 affected the results.

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## 1 V. RESULTS

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### 3 A. Effects of noise level on performance

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#### 5 1. Experiment 1: performance in 50 dB and 70 dB

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7 The results of Experiment 1 are shown in Table II. Students attempted an average of 11.85  
8 questions ( $SD$  2.45) in the 50 dB condition and 11.31 questions ( $SD$  3.28) in the 70 dB  
9 condition, out of a possible maximum of 20 questions. As Table II shows, in general, there  
10 were more correct answers to all question types and longer reading times and latencies in the  
11 50 dB condition than in 70 dB  $L_{Aeq}$ . Overall, older pupils provided more correct answers,  
12 with faster response times, as would be expected.

13

14 The effect of both noise level and age was examined. A MANOVA revealed statistically  
15 significant main effects of noise level ( $V = 0.08$ ,  $F(8, 642) = 6.53$ ,  $p < 0.001$ ,  $P\eta^2 = 0.08$ ),  
16 and of age group ( $V = 0.12$ ,  $F(8, 642) = 11.37$ ,  $p < 0.001$ ,  $P\eta^2 = 0.12$ ), indicating differences  
17 in performance in the two noise conditions, and between the two age groups. There was also  
18 a statistically significant interaction between noise level and age group ( $V = 0.04$ ,  $F(8, 642)$   
19  $= 3.41$ ,  $p < 0.001$ ,  $P\eta^2 = 0.04$ ), showing that noise had differing impacts on the two age  
20 groups. Follow up ANOVAs revealed statistically significant effects of noise level on the  
21 number of questions attempted ( $F(1, 649) = 4.08$ ,  $p = 0.044$ ,  $P\eta^2 = 0.01$ ); correct responses  
22 to the factual questions ( $F(1, 649) = 6.53$ ,  $p = 0.01$ ,  $P\eta^2 = 0.01$ ); and correct responses to the  
23 word learning question ( $F(1, 649) = 3.94$ ,  $p = 0.048$ ,  $P\eta^2 = 0.01$ ), with, overall, more correct  
24 responses to both types of question in the 50 dB condition. There was also a statistically  
25 significant effect of noise level on latency for the word learning question ( $F(1, 649) = 7.98$ ,  $p$   
26  $= 0.005$ ,  $P\eta^2 = 0.01$ ), with longer latencies in the lower noise condition of 50 dB  $L_{Aeq}$ . The  
27 difference in article reading times between the two conditions approached significance ( $F(1,$   
28  $649) = 3.69$ ,  $p = 0.055$ ,  $P\eta^2 = 0.01$ ), with longer reading times in the lower, 50 dB  $L_{Aeq}$ ,

1 condition. There were no statistically significant effects of noise level on correct responses to  
2 inferential questions, or response latencies for factual or inferential questions ( $F < .84$ ,  $p >$   
3  $0.163$  in all cases). Thus, in sum pupils were significantly more accurate for responses to  
4 factual and word learning questions, spent more time reading and were slower to respond in  
5 the quieter condition.

6

7 Performance of the two different age groups was examined using follow up ANOVAs and  
8 yielded statistically significant effects of age for the number of questions attempted ( $F (1,$   
9  $649) = 6.43$ ,  $p = 0.010$ ,  $\eta^2 = 0.01$ ), where the older group provided more correct answers to  
10 both factual ( $F (1, 649) = 26.20$ ,  $p < 0.001$ ,  $\eta^2 = 0.04$ ) and inferential ( $F (1, 649) = 24.45$ ,  $p$   
11  $< 0.001$ ,  $\eta^2 = 0.04$ ) questions, and word learning ( $F (1, 649) = 21.83$ ,  $p < 0.001$ ,  $\eta^2 =$   
12  $0.03$ ). There was also a statistically significant effect of age on response latencies to factual  
13 questions ( $F (1, 649) = 24.56$ ,  $p = 0.030$ ,  $\eta^2 = 0.01$ ) and word learning ( $F (1, 649) = 48.45$ ,  
14  $p < 0.001$ ,  $\eta^2 = 0.01$ ) with the latencies being longer in the younger age group. There were  
15 no effects of age on article reading times or latencies for inferential questions ( $F < .81$  and  $p$   
16  $> .025$  in both cases). Overall, older pupils attempted more questions and answered more  
17 questions correctly than the younger ones, and their response latencies to factual and word  
18 learning questions were shorter than those of the younger age group.

19

20 Examining the differential impact of noise on the two age groups, there was a statistically  
21 significant interaction between noise level and age group for correct answers to factual  
22 questions ( $F (1, 649) = 14.63$ ,  $p < 0.001$ ,  $\eta^2 = 0.01$ ). As can be seen in Table II performance  
23 on factual questions by the older age group was better than that of the younger age group in  
24 both noise conditions; however, the older pupils were less accurate in the 70 dB  $L_{Aeq}$  than in  
25 the 50 dB  $L_{Aeq}$  condition, whereas younger pupils were more accurate at 70 dB  $L_{Aeq}$ . Separate



1 analyses for each age group revealed a significant effect of noise condition for the older  
2 pupils on factual questions ( $F(1, 307) = 19.73, p < 0.001, \eta^2 = 0.06$ ), but a non significant  
3 effect of noise condition on factual questions in the younger pupils ( $F(1, 347) = .666, ns$ )  
4 ,There were no other significant noise/age group interactions ( $F < 3.00$  and  $p > 0.25$  in all  
5 other noise condition/age group ANOVAs.

6  
7 In sum, there were statistically significant effects of classroom noise level on reading  
8 comprehension. Overall, performance was less accurate in the 70 dB condition compared to  
9 the 50 dB condition, and this difference was statistically significant for the number of correct  
10 responses to factual questions and word learning questions. Time taken to read and process  
11 the information was also affected by classroom noise level: there was a trend for response  
12 latencies to be longer in the 50 dB condition, especially for the younger pupils, and this effect  
13 was statistically significant for response latencies to word learning questions. There was also  
14 a differential impact of condition on each of the age groups: accurate responding in the older  
15 age group was more negatively impacted in the louder condition compared to the younger age  
16 group, whereas reading times and response latencies were longer in the quiet condition for  
17 the younger but not the older age group.

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20 **2. Experiment 2: performance in 50 dB and 64 dB**

21  
22 Table III presents the results of the students' performance in the 50 dB  $L_{Aeq}$  condition and the  
23 64  $L_{Aeq}$  dB conditions. MANOVA revealed statistically significant main effects of noise  
24 level ( $V = 0.08, F(8, 290) = 3.02, p = 0.003, \eta^2 = 0.08$ ), and of age group ( $V = 0.09, F(18,$   
25  $290) = 2.42, p = 0.005, \eta^2 = 0.09$ ). There was also a statistically significant interaction  
26 between noise level and age group ( $V = 0.08, F(12, 290) = 2.05, p = 0.021, \eta^2 = 0.08$ ).  
27 Follow up ANOVAs revealed a statistically significant effect of noise condition on the

1 number of questions attempted ( $F(1, 301) = 4.09, p = 0.044, P\eta^2 = 0.01$ ), with more  
2 questions attempted in the 50 dB condition. There were no significant effects of noise  
3 condition on any other measure ( $F < 3.00$  and  $p > 0.15$  in each case).  
4  
5 By contrast, overall, there was a significant effect of age on the following measures, where  
6 performance by the older age group was better than that of the younger age group; number of  
7 questions attempted  $F(1, 301) = 11.407, p < 0.001, P\eta^2 = 0.04$ , factual questions  $F(1, 301) =$   
8  $5.43, p = .02, P\eta^2 = 0.02$ , inferential questions  $F(1, 301) = 12.64, p < 0.001, P\eta^2 = 0.04$ , word  
9 learning  $F(1, 301) = 4.24, p = .04, P\eta^2 = 0.01$ , reading time  $F(1, 301) = 10.787, p < 0.001$   
10  $P\eta^2 = 0.04$ , response latency to factual ( $F(1, 301) = 9.555, p = 0.002, P\eta^2 = 0.03$ ), inferential  
11 ( $F(1, 301) = 14.147, p < 0.001, P\eta^2 = 0.05$ ) and word learning ( $F(1, 301) = 10.290, p < 0.001$   
12  $P\eta^2 = 0.03$ ) questions.  
13  
14 There was also a significant noise level/age group interaction for the number of questions  
15 attempted ( $F(1, 301) = 7.70, p = 0.006, P\eta^2 = 0.03$ ), correct responses to the factual  
16 questions ( $F(1, 301) = 5.76, p = 0.02, P\eta^2 = 0.02$ ), inferential questions ( $F(1, 301) = 4.43, p$   
17  $= 0.036, P\eta^2 = 0.01$ ) and word learning questions ( $F(1, 301) = 12.38, p = 0.001, P\eta^2 = 0.04$ )  
18 ANOVAs for each age group indicated that for the younger group there were no significant  
19 differences for inferential questions or total attempts between the two noise conditions ( $F <$   
20  $2.5$  and  $p > 0.11$  in each case), while they performed significantly better at 64 dB  $L_{Aeq}$  in both  
21 the factual ( $F(1, 201) = 7.54, p = 0.007, P\eta^2 = .04$ ) and word learning tasks ( $F(1, 201) =$   
22  $7.00, p = 0.009, P\eta^2 = .03$ ) For the older group there were no significant differences for  
23 factual or inferential questions ( $F < 2.0$  and  $p > 0.15$  in each case), whereas total number of  
24 attempts ( $F(1, 103) = 5.51, p = 0.02, P\eta^2 = .06$ ), and word learning ( $F(1, 103) = 6.10, p =$   
25  $0.015, P\eta^2 = .04$ ), were significantly better in the 50 dB  $L_{Aeq}$  condition.

1 There was also a statistically significant noise level/age group interaction for article reading times ( $F$   
2 (1, 301) = 9.64,  $p = 0.002$ ,  $\text{Pr}^2 = 0.03$ ). Pupils in the younger group read significantly faster in the 64  
3 dB  $L_{\text{Aeq}}$  condition ( $F$  (1, 201) = 7.78,  $p = 0.006$ ,  $\text{Pr}^2 = .04$ ) whereas older pupils read significantly  
4 slower at 64 dB  $L_{\text{Aeq}}$  ( $F$ (1, 103) = 4.60,  $p = 0.034$ ,  $\text{Pr}^2 = .04$ ), Overall, the noise level/age  
5 interactions reveal that the older age group's performance was negatively impacted by the 64 dB  $L_{\text{Aeq}}$ ,  
6 noise condition, compared with 50 dB  $L_{\text{Aeq}}$  but the younger age group performed better at 64 dB  $L_{\text{Aeq}}$   
7 .To summarise, over all pupils more questions were attempted in the 50 dB  $L_{\text{Aeq}}$  condition,  
8 however, the follow up ANOVAs revealed no statistically significant differences in overall  
9 performance between the 50 dB  $L_{\text{Aeq}}$  and 64 dB  $L_{\text{Aeq}}$  conditions. As expected, there were  
10 statistically significant differences between age groups on all measures. Where differences by  
11 age group between the noise conditions were found the 64 dB  $L_{\text{Aeq}}$  condition reduced  
12 performance for the older group and increased performance for the younger group. In  
13 general, response latencies decreased in the higher noise level, apart from responses to factual  
14 questions for the older age group.

15  
16

## 17 **B. Effects of order of testing on performance**

18

19 As explained in section IVA, in each experiment half the participants received the quieter  
20 noise level first and half were tested first in the louder condition. To examine the stability of  
21 the effects of noise exposure, results of each experiment were investigated to see if the order  
22 in which the two noise conditions were presented affected performance. For each experiment  
23 individual changes in scores between the two test times were examined. For each participant  
24 the difference between the number of questions attempted, accuracy, response latency, text  
25 reading times and coefficient of variance at the two times of testing were calculated. These  
26 difference scores were entered as dependent variables into a MANOVA with condition order  
27 and age group as between participant variables.

28

1 For Experiment 1 there was no effect of order on accuracy. There was a significant order/age  
2 interaction on stability of performance ( $F(8, 642) = 5.65, p < 0.001, \eta^2 = 0.07$ ), indicating  
3 that, although pupils in both condition orders attempted more questions on the second time of  
4 testing, the older children who received the 50 dB  $L_{Aeq}$  condition first attempted significantly  
5 more questions in the 70 dB  $L_{Aeq}$  condition than those who received the louder condition first  
6 ( $F(1, 649) = 4.84, p = 0.028, \eta^2 = 0.07$ ), an average difference of 1.2 questions. Thus,  
7 overall, the impact of the noise conditions was independent of the order of testing with an  
8 indication that, for older pupils only, completing the task in the quieter condition first resulted  
9 in more attempts to answer in the louder condition.

10

11 In Experiment 2, the only effects of order were greater increases in reading time ( $F(1, 297) =$   
12  $6.39, p = 0.012, \eta^2 = 0.02$ ) and latency for inferential questions ( $F(1, 297) = 65.82, p =$   
13  $0.016, \eta^2 = 0.02$ ) for those tested first in the quieter condition. As in experiment 1, there was  
14 no effect of order on accuracy.

15

## 16 VI. DISCUSSION

17 This study has shown that high levels of classroom noise can have disruptive effects upon  
18 secondary school pupils' performance on short time limited reading tasks, particularly on  
19 reading comprehension and word learning. Negative effects were pronounced at levels of 70  
20 dB  $L_{Aeq}$ , when compared with performance at the lower level of 50 dB  $L_{Aeq}$ . By contrast  
21 results at 64 dB  $L_{Aeq}$  in comparison 50 dB  $L_{Aeq}$  were conflicting: the accuracy and  
22 processing time of the older pupils were impaired but performance of the younger pupils was  
23 not. For some measures younger pupils performed better in the 64 dB  $L_{Aeq}$  condition.

24

1 Thus there were differences in the ways in which the older and younger age groups were  
2 affected by noise. Both experiments showed that the higher levels of noise had a negative  
3 impact upon the older (14 to 16 years) compared to the younger (11 to 13 years) pupils. The  
4 decrease in numbers of questions attempted and numbers of correct responses was  
5 significantly greater for the older age group than the younger when comparing performance  
6 in both 70 dB  $L_{Aeq}$  and 64 dB  $L_{Aeq}$  with 50 dB  $L_{Aeq}$ . However, the response latencies for the  
7 older group were generally the same in the lower and higher noise levels in both experiments  
8 whereas for the younger group they were longer in the lower noise level, possibly reflecting  
9 the more efficient reading processes of the older pupils.

10

11 When comparing performance in levels of 50 dB  $L_{Aeq}$  and 70 dB  $L_{Aeq}$ , overall pupils  
12 attempted fewer questions, and responses to questions and word learning were less accurate  
13 at 70 dB  $L_{Aeq}$ . Taking into account reading times and response latencies, the results suggest  
14 that better accuracy was underpinned by a speed/accuracy trade-off. Response latencies for  
15 word learning questions in the 70 dB  $L_{Aeq}$  condition were significantly shorter than in the 50  
16 dB  $L_{Aeq}$  condition, and performance was less accurate, while there was also a non-significant  
17 tendency towards shorter article reading time in the 70 dB  $L_{Aeq}$  condition. Thus the 70 dB  
18  $L_{Aeq}$  condition significantly affected processing efficiency, where pupils were less accurate  
19 but faster. The finding that lower classroom noise levels tended to produce longer reading  
20 times and response latencies suggests that participants were enabled to focus on the task in  
21 hand. Such strategies might include reading more slowly and carefully, re-reading difficult  
22 passages or unfamiliar words, and pausing to reflect and make appropriate inferences. This is  
23 consistent with the view of reading as a complex, multi-component process (Hannon and  
24 Daneman, 2001; Oakhill *et al*, 2003; Cain *et al*, 2001; Graesser *et al*, 1994), with different  
25 skills being differentially affected by unfavourable levels of noise. The results are also

1 consistent with experimental studies demonstrating the ISE, where processing of the written  
2 text was disrupted by the unattended oral stimuli (Elliott, 2002; Joseph *et al*, 2018). Further  
3 work needs to establish the impact of extended exposure to high levels of classroom noise, but  
4 the current data clearly indicate that such levels impact on reading.

5  
6 When comparing performance by the two age groups in 50 dB  $L_{Aeq}$  and 64 dB  $L_{Aeq}$ , that of  
7 the older age group was, in general, better in the 50 dB condition, but the size of this  
8 advantage was not as large in the 64 dB condition. Older pupils spent significantly more time  
9 reading in the 64 dB  $L_{Aeq}$ . Overall, their performance in the 50 dB  $L_{Aeq}$  condition was better,  
10 with significant negative effects at 64 dB  $L_{Aeq}$  for the number of questions attempted and  
11 numbers of new words learnt. Performance by the younger age group in the 64 dB condition  
12 was not negatively affected, and, unexpectedly, in some of the tasks the higher noise level  
13 appeared to have a positive effect upon this age group, although results were often not  
14 statistically significant. While inconsistent with previous research on listening comprehension  
15 (Klatte *et al*, 2010), older pupils' susceptibility to high noise levels is consistent with results  
16 of a survey of adolescents' perceptions of school acoustical environments, in which older  
17 pupils expressed more sensitivity to noise in school and its negative consequences (Connolly  
18 *et al*, 2013) and the greater potential cognitive engagement in the tasks expected for older  
19 pupils.

20

21 It was found that condition order did not affect accuracy of performance on any measure. The  
22 lack of significant order effects speaks to the reliability of the conclusions as they hold across  
23 noise levels irrespective of order of testing. This has important implications for the acoustic  
24 design of high schools where pupils are likely to move between settings with different noise

1 levels. The current data suggest that noise in the context of a school's acoustical environment  
2 will impact on task success and cognitive processing.

3

4 In both experiments, the effect sizes for condition were small but statistically significant.

5 These small effect sizes are comparable to those reported in other classroom studies into the  
6 effects of noise on pupils' learning with younger pupils (Dockrell and Shield, 2006), and may  
7 reflect the heterogeneous nature of pupils in typical school classrooms. In addition, the design  
8 of the reading task minimized the amount of time that information had to be held in short-  
9 term memory, as questions were presented immediately after each short section of text; this  
10 may partially explain the small effect sizes observed. Nonetheless the effect of noise on a  
11 short time limited reading task speaks to the pervasiveness of adverse noise conditions on  
12 pupil performance.

13

14 The research differs from previous studies into the effects of auditory distraction on reading  
15 processes, which have focused on the disruptive effects of speech-like distractors on adults'  
16 reading comprehension (Martin *et al*, 1988; Oswald *et al*, 2000; Sorqvist *et al*, 2010); or on  
17 high school students' comprehension while exposed to variable noise sources (Hygge *et al*,  
18 2003) and white noise (Soderlund *et al*, 2010). By using real classroom noise stimuli that did  
19 not feature identifiable, individual speech signals pupils were provided with a situation which  
20 reflected their current classroom environments. In this context, the use of response latencies  
21 has shown promise as a tool to investigate the effects of unfavourable noise levels on  
22 heterogeneous groups of learners.

23

24 The data also contribute to our understanding of the way development moderates the effect of  
25 noise. Previous studies have consistently reported that younger pupils are more affected by

1 noise than adults (Elliott and Briganti, 2012; Klatte *et al*, 2010; Meinhardt-Injac *et al*, 2015).  
2 However, in the majority of cases these studies have compared performance between  
3 elementary school pupils and college students or small groups of elementary school students  
4 (Meinhardt-Injac *et al*, 2015). The current study demonstrates that, in a large sample of high  
5 school students using realistic and demanding time limited tasks, accuracy and processing  
6 were more affected in the older pupils. One possible explanation for this is that older pupils  
7 were more engaged with the task and therefore more influenced by the noise distraction.  
8 Alternatively, older pupils may be more aware of the need to spend time processing new  
9 material and this approach to reading was negatively affected in the noisier conditions. These  
10 results suggest that claims of developmental differences require carefully matched samples  
11 examining different age bands throughout the years of compulsory schooling using realistic  
12 classroom tasks measuring a range of different outcomes.

13

## 14 **VII. IMPLICATIONS FOR THE ACOUSTIC DESIGN OF SCHOOLS**

15 The levels at which the noise was presented in the experiments represent the differences  
16 between good and poor acoustical conditions observed in high school classrooms. The  
17 findings reported provide an insight into the negative impact of poor classroom acoustics on  
18 reading comprehension for this age group. Clear detrimental effects were observed in  
19 classroom noise levels of 70 dB  $L_{Aeq}$ , particularly for the older children aged 14 to 16 years.  
20 The older children also demonstrated adverse effects of noise in the lower noise level of 64  
21 dB  $L_{Aeq}$ . This is of concern as these levels are typical of the noise levels found during lessons  
22 in English high school classrooms (Shield *et al*, 2015) and in other surveys (for example  
23 Lundquist *et al*, 2000; Shield and Dockrell, 2004; Avsar and Gonullu, 2010).

24



1 It is therefore important to design schools so that classroom noise is kept to a minimum,  
2 ideally below 64 dB  $L_{Aeq}$ , given the negative impact of the 64 dB  $L_{Aeq}$  condition on the older  
3 pupils. The secondary school noise survey by Shield *et al* (2015), which measured noise  
4 levels during nearly 300 lessons in 80 classrooms, found that there was a significant  
5 correlation between lesson noise levels and unoccupied ambient levels. The unoccupied level  
6 corresponding to 64 dB  $L_{Aeq}$  was found to be 35  $L_{Aeq}$ , which is the maximum level required  
7 for unoccupied classrooms under the current UK regulations (Department for Education,  
8 2015). Thus schools must be designed to meet current requirements, to ensure that noise  
9 levels do not exceed those known to have a detrimental effect upon pupils' reading  
10 comprehension.

11

## 12 **VIII. CONCLUSIONS**

13 High school pupils are sensitive judges of the facilitation of teaching and learning that occurs  
14 when classroom acoustics are good (Astolfi and Pelleray, 2008; Connolly *et al*, 2013).  
15 However, until now there has been a lack of research into the disruption of learning processes  
16 caused by poor classroom acoustics in this age group. The present study has produced  
17 evidence that adolescent learners' reading comprehension is adversely affected by high levels  
18 of classroom noise. Disruption was evident at 70 dB, but the finding that negative effects are  
19 also evident at 64 dB for older pupils is a cause for concern, as this represents the average  
20 level of noise in secondary school classrooms (Shield *et al*, 2015). One finding in particular  
21 went against expectations: pupils in the older age group were more affected by high levels of  
22 classroom noise than pupils in the younger age group. Lower noise levels appeared to  
23 provide students with the opportunity for longer processing time, which resulted in greater  
24 accuracy. This study adds to the body of evidence underlining the importance of good

1 classroom acoustics for learning by demonstrating that adolescents' reading comprehension is  
2 vulnerable to the challenges created by unfavorable levels of classroom noise.

3  
4

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7 funding this project, and the schools, pupils and teachers who have participated in the study.

8

### 9 **APPENDIX: EXAMPLE OF READING TEST**

10

#### 11 **ENDOCRINOLOGY – THE STUDY OF HORMONES**

12 Scientists have discovered that a weed killer called atrazine can make male frogs act like  
13 females. They studied male frogs raised in a tank containing a weak concentration of atrazine.

14 One third of the frogs started sending out chemical signals to attract other males just like  
15 females do.

16 1. Why did the male frogs in the study send out chemical signals?

- 17 a) To attract females  
18 b) To act like weed killer  
19 c) To attract males  
20 d) To act like male frogs

21 Scientists also found that some of the frogs actually turned into females. Four out of every  
22 hundred frogs had high levels of a female hormone called oestrogen. Some of these frogs  
23 were introduced to healthy males. They mated with the males and produced baby frogs.

24 2. What is oestrogen?

- 25 a) A weed killer

1 b) A female hormone

2 c) A male hormone

3 d) A high level hormone

4 3. How does atrazine cause some frogs to change sex?

5 a) By making them pregnant

6 b) By raising their level of oestrogen

7 c) By making them mate with males

8 d) By raising their levels of male hormone

9 Farmers use atrazine because it's an effective weed killer. But it can pollute streams near  
10 farms where it is used. In some streams the concentration of atrazine can reach two and a half  
11 parts per billion. The government says that up to three parts per billion of atrazine is safe.  
12 This is more than the amount that turned some of the males into females in the study.

13 4. What does this study show about the legal amount of atrazine?

14 a) It is too high

15 b) It is just right

16 c) It is two parts per billion

17 d) It is too low

18 5. What is the study of hormones called?

19 a) Haematology

20 b) Oestropology

21 c) Endocrinology

22 d) Escapology

23

24

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TABLE I. Details of pupils in Experiments 1 and 2

Age years	Experiment 1		Experiment 2	
	N	%	N	%
11	83	12.4	37	12.1
12	145	21.7	133	43.3
13	133	20	33	10.7
14	141	21	70	22.8
15	104	15.5	34	11.1
16	63	9.4	0	0
All	669	100	307	100
	N	Mean age (sd)	N	Mean age (sd)
11 - 13	361	12.14 (0.76)	203	11.98 (0.59)
14 - 16	308	14.75 (0.78)	104	14.33 (0.47)
All	669	13.34 (1.5)	307	12.78 (1.24)

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TABLE II: Results of Experiment 1: means and standard deviations of number of questions attempted; correct answers; and time-based measures, showing statistically significant differences between noise levels

	Question type (Maximum score)	Age group	Noise condition			
			50 dB		70 dB	
			Mean	sd	Mean	sd
Number of questions attempted	(20)	11 – 13	11.44	2.25	11.15	3.44
		14 – 16	12.20	2.57	11.55	3.02
		All*	11.85	2.45	11.31	3.28
Accuracy	Factual (8)	11 – 13	2.59	1.26	2.73	1.36
		14-16****	3.52	1.38	2.86	1.18
		All**	3.10	1.40	2.78	1.29
	Inferential (8)	11 – 13	1.84	1.27	1.81	1.34
		14 – 16	2.38	1.31	2.30	1.27
		All	2.13	1.32	2.01	1.33
	Word Learning (4)	11 – 13	0.93	0.78	0.80	0.75
		14 – 16	1.20	0.76	1.09	0.77
		All*	1.08	0.78	0.92	0.77
Article Reading Time (s)		11 – 13	21.9	9.0	20.3	8.9
		14 – 16	21.0	8.2	20.3	7.2
		All	21.4	8.6	20.3	8.2
Response Latencies (s)	Factual	11 – 13	8.1	5.1	7.8	4.2
		14 – 16	6.9	3.5	7.0	3.9
		All	7.5	4.3	7.4	4.1
	Inferential	11 – 13	9.5	5.4	8.9	4.6
		14 – 16	8.9	4.3	9.1	4.6
		All	9.2	4.8	9.0	4.6
	Word Learning	11 – 13	8.7	4.8	7.2	3.1
		14 – 16	6.2	3.5	5.9	3.2
		All***.	7.4	4.3	6.7	3.2

Statistical significance: \*  $p < 0.05$ ; \*\*  $p < 0.01$ ; \*\*\*  $p < 0.005$

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TABLE III: Results of Experiment 2: means and standard deviations of number of questions attempted; correct answers; and time-based measures, showing statistically significant differences between noise levels

	Question type (Maximum score)	Age group	Noise condition			
			50 dB		64 dB	
			Mean	sd	Mean	sd
Number of questions attempted	(20)	11 – 13	11.25	1.94	11.48	2.87
		14 -16*	13.18	3.20	11.67	2.59
		All* .04	11.71	2.43	11.57	2.74
Accuracy	Factual (8)	11 –13 <sup>+</sup>	3.14	1.28	3.64	1.38
		14 – 16	3.95	1.37	3.63	1.49
		All	3.33	1.34	3.64	1.43
	Inferential (8)	11 – 13	2.08	1.06	2.35	1.26
		14 – 16	2.95	1.31	2.56	1.31
		All	2.29	1.17	2.45	1.29
	Word Learning (4)	11 –13 <sup>+</sup>	1.00	0.76	1.30	0.85
		14 - 16**	1.55	0.69	1.16	0.90
		All	1.13	0.78	1.24	0.87
Article Reading Time (s)		11 –13 <sup>+</sup>	22.5	7.0	19.9	6.2
		14 -16*	17.5	6.1	20.0	6.2
		All	21.3	7.1	19.9	6.2
Response Latencies (s)	Factual	11 – 13	7.2	3.9	7.0	3.0
		14 – 16	5.6	1.2	6.3	2.1
		All	6.8	3.5	6.7	2.6
	Inferential	11 – 13	10.4	9.0	9.1	4.0
		14 – 16	7.6	2.4	7.4	2.6
		All	9.7	8.0	8.3	3.5
	Word Learning	11 – 13	7.3	3.8	6.6	4.2
		14 – 16	5.8	2.4	5.5	1.9
		All	6.9	3.6	6.1	3.4

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Statistical significance: \* $p < 0.05$ ; \*\* $p < 0.01$   
<sup>+</sup> performance better at higher noise level,  $p < 0.01$